(16.)

RESEARCHES

ON THE

ACTION OF THE HEART.

BY

GEORGE PATON, M.D.

[Reprinted from the Dublin Quarterly Journal of Medical Science, August, 1866.]

DUBLIN:
JOHN FALCONER, 53, UPPER SACKVILLE-STREET,
Printer to Her Majesty's Stationery Office.

1866.

RESEARCHES

ON THE

ACTION OF THE HEART.

If we expose the heart in a living animal, and examine its action, we will find that the auricles contract whilst the ventricles dilate, and the ventricles contract whilst the auricles dilate, and are refilled with blood from the veins. The auricles, in contracting, approximate closely to the ventricle—shoot, as it were, into the auriculo-ventricular foramen, projecting the blood into the cavity of the ventricle, and the ventricle expands, swells out, and becomes distended with blood, assuming a dark red colour. These two movements—the contraction of the auricles and the dilatation of the ventricles—appear simultaneous, being performed at the same instant of time; the ventricle then contracts, diminishing in all its dimensions, propelling the blood along the aorta and pulmonary arteries, synchronous with which the auricles dilate, and receive more blood from the venous trunks.

The auricles, in contracting, approach closely to the orifice of the ventricle, which enables them with greater facility to project the blood into its cavity. This is distinctly seen in the heart of the turtle, where the auricles in contracting shoot towards the foramen of the ventricle, leaving vacant at their upper extremity a portion of space which they occupied, but which they again immediately cover, as they stretch out and extend their parietes during dilatation. The ventricle, in dilating, enlarges in all its dimensions, its apex descends a little lower in the thorax, dipping towards the spine; its transverse diameter is increased, and anterior parietes rendered protuberant; and in some animals the margin of the base is extended upwards,

so as partly to cover or conceal the auricles during their contraction. When the ventricle contracts its apex is again drawn up and slightly tilted forwards, and the body of the ventricle, much diminished in size, appears distinct from the auricles which have receded, and are again dilated, the blood flowing into them from the veins.

When the heart pulsates with vigour, and respiration is well maintained, rendering the blood duly arterialized, the contraction of the ventricle is scarcely finished before the auricles again contract and shoot a wave of blood into the ventricle, as it expands, and quickly attains its maximum of dilatation. It immediately contracts whilst the auricles dilate; and these movements occur in rapid succession, the eye being scarcely able to follow them, and analyze them distinctly; but after careful investigation and numerous experiments, we are satisfied that during this state of the system the dilatation of the ventricle is one distinct or individual act quickly performed, and that no pause or period of repose occurs during its completion. If, however, the action of the heart be slow, and the blood imperfectly arterialized the dilatation of the ventricle attains a pause before the auricles contract; and on their contraction the blood which they project into the cavity of the ventricle distends its walls, or, in other words, completes the dilatation—which phenomenon is distinctly seen in cold-blooded animals when the circulation is languid, the pulsations of the heart not exceeding 20, 25, or 28 per minute.

The circumstance of a pause occurring during the dilatation of the ventricle, in connexion with other phenomena observed in the action of the heart has led physiologists to conclude that it is only during the contraction of the ventricle that an active power is exerted, and not during its dilatation. Accordingly, it is an opinion very generally entertained by physiologists that the diastole of the ventricle is produced by the relaxation of the muscular fibres—by their returning to a state of rest, during which the blood flows from the distended auricles into the cavity of the ventricle independently of contraction; that a pause then ensues, succeeded by the contraction of the auricles projecting more blood into the ventricle, and bringing it into a state of distention; hence the dilatation of the ventricle is supposed to consist of two stages: during the first stage the blood flows from the auricles into the cavity of the ventricle to supply the vacuum that is formed by the receding walls of the ventricle as it assumes a state of rest; during

the second stage, the blood is propelled by the contraction of the auricles into the ventricle already partially filled to complete the dilatation. But during both these stages the ventricle is supposed to exist in a passive or relaxed condition.

This view has been very distinctly expressed by Dr. Hope in his *Analysis of the Movements of the Heart.* He divides, as did Lænnec, a beat of the heart into several parts—that is, from the commencement of one pulsation to the corresponding period in the next:—"1st. The ventricular systole occupies half the time, or thereabouts, of a whole beat. 2nd. The ventricular diastole occupies a fourth, or at most a third. 3rd. The interval of ventricular repose occupies a fourth, or rather less, during the latter half of which the auricular systole takes place." This makes a whole beat consist of four parts. The ventricular systole occupies two-fourths of a beat, the ventricular diastole one-fourth, and the period of repose one-fourth, during the latter half of which the auricle contracts, projecting the blood into the ventricle, thus allowing one-eighth of a beat for the period in which it is performed.[a]

The data on which these conclusions rest appear to have been limited to the action of the heart when it is slow, and the blood imperfectly arterialized; at least this is the description of the action of the heart of an animal in that condition. This phenomenon is distinctly seen in cold-blooded animals during the period of Winter, or when they are reduced to a state of partial asphyxia, the action of the heart being much depressed, amounting to ten or twelve pulsations per minute. In the frog, to which Dr. Hope's observations refer, the ventricle, on contracting, immediately dilates, its apex being extended a little lower, and its parietes expanding, so that blood flows into the cavity from the auricles, partially distending it. A pause then ensues, during which the ventricle and auricles remain quiescent; the auricles then contract, propelling more blood into the ventricle, which causes the anterior parietes to bulge out or protrude slightly in the centre—on which the ventricle immediately contracts, becomes small and pale, propelling the blood along the aorta or bulbus arteriosus, as it is termed; and these movements continue in regular succession. But if the animal respire at times the action of the heart is accelerated, amounting to

[a] Dr. Hope on Diseases of the Heart, p. 20.

fifteen or twenty pulsations in the minute, the pause becomes shorter, and the movements are performed with greater vigour.

If we were permitted to reason *a priori*, we might conclude that the action of the heart, which is suited to a condition of the system in which all the functions are depressed, would not be adapted to the circulation of an animal whose heart beats at 60, 80, or 90 pulsations per minute—the blood moving with great velocity, and passing through the heart once every three or four minutes, or twenty times in the hour. But science requires data founded on strict observation, and a rigid induction of facts; and many physiologists, in order to determine this question, have observed the action of the heart in living animals whose respiration was fully maintained, and the circulation vigorous, and have failed to perceive the pause or the two stages of dilatation. Majendie, who frequently denuded the heart of living animals, observes that the action of the auricles and ventricles alternate, but makes no mention of a pause. And Professor Cruveilhier, who had an opportunity of investigating this subject in the case of a child whose heart was protruded without the walls of the chest—the auricles and ventricles dilating and contracting with vigour, and respiration being fully established, states:—1st. That the contraction of the auricles was synchronous with the dilatation of the ventricles. 2nd. That no pause or period of repose occurred during the dilatation of the ventricle. 3rd. That the auricles and ventricles dilated with a force, which afforded every indication of being an active vital movement.

And our researches on the action of the heart in living animals lead us to conclude:—1st. That when the action of the heart is slow, and the blood imperfectly arterialized, a pause occurs during the dilatation of the ventricle. 2nd. When the action of the heart is vigorous the pause disappears, and the dilatation of the ventricle takes place simultaneously with the contraction of the auricles. 3rd. That the diastole affords evidence of being an active power as well as the systole.

When the blood is highly arterialized, and the action of the heart vigorous, the dilatation of the ventrical consists of an individual, or continuous act quickly performed in unison with the contraction of the auricles. If we examine the action of the heart under these circumstances, as the heart of a frog, we will perceive that the contraction of the auricles is synchronous with the dilatation of the ventricle, which annihilates the pause; and that

the ventricle as it dilates not only extends its apex a little lower, but rapidly stretches its parietes upwards, so as almost to conceal the auricles, as they contract, and project the blood into its cavity—a movement opposed to that of relaxation, and evidently dependent on some inherent power possessed by the ventricle itself. And if we observe the dilatation of the auricles, as it appears in the heart of the turtle, we will find that it consists in a rapid extension of the parietes in a longitudinal form till they have attained or reached their extreme limit, thus enlarging the capacity of the auricles as the blood flows into them from the veins.

And the increased rapidity with which the ventricle dilates, as the circulation of the blood is accelerated, could not be explained on the principle of relaxation, but decidedly indicates a vital active movement.

If the heart pulsates at the rate of thirty beats per minute, or one beat in two seconds, the contraction of the ventricle, according to Dr. Hope and others, occupies one half of this period or one second; and the first stage of the dilatation, which is described as taking place instantaneously, occurs in one-fourth of the beat, or half a second—considered to be dependent on the relaxation of the fibres of the ventricle, bringing it into a state of rest; the remaining one-fourth of the beat, or the half second, being occupied by the pause or period of repose, and the contraction of the auricles, increasing the amount of blood contained in the cavity of the ventricle, and bringing it to a state of distention. If the heart pulsates at the rate of sixty beats per minute, or one beat per second, the contraction of the ventricle occupies one half of this period, or takes place in half a second, and with twice as great velocity as when the ventricle contracts at thirty beats per minute; and the first stage of the dilatation which occupies one-fourth of a beat is also accomplished in one-half the time, or with double the velocity that it is when the heart beats at thirty pulsations per minute, the remaining one-fourth of the beat being occupied by the period of repose, and the auricles contracting at double the velocity, bringing the ventricle to a state of distention; and if the heart pulsates at the rate of ninety beats per minute, or three beats in two seconds, the ventricle contracts at the rate of three times the velocity that it does when the heart pulsates at thirty beats per minute; and the ventricle also dilates with three times greater rapidity, showing that the dilatation of the ventricle is regulated by exactly the same influence and under the

same law as its contraction, and that its diastole is as much an active power as its systole.

If the dilatation of the ventricle takes place with various degrees of rapidity, according to the force and velocity with which the ventricle contracts, and in order that the circulation may be carried on at a certain rate of speed, then, it must be the result of a vital power as well as the contraction, and not the mere passive relaxation of the muscle. Again, if the dilatation of the ventricle be accomplished in one-third of the time, the heart beating at ninety per minute, that it is when the heart pulsates at thirty per minute; it follows that the blood must pass from the auricle into the ventricle and distend it in this minimum period. But if there be two stages of the dilatation, the auricle contracting during the latter half of the second stage, it leaves at this rate of speed the auricle only one-twelfth of a second to contract and complete the dilatation of the ventricle, a rapidity at variance with all that we have seen of the contraction of the auricle and dilatation of the ventricle during a similar state of the circulation. For when the blood moves with great velocity, the contraction of the auricle commences simultaneously with the dilatation of the ventricle, and the ventricle without any intermission speedily attains its maximum of dilatation.

Whilst the circulation is maintained at this degree of rapidity, the dilatation of the ventricle in order of rhythm and of time precedes its contraction. For the contraction of the auricles, as is well known, takes place before that of the ventricles; and as the dilatation of the ventricles is synchronous with the contraction of the auricles, it is evident that it must be considered to precede and not to follow the systole of the ventricle. When the heart pulsates at the rate of sixty beats a minute, a speed similar to what obtains in many warm-blooded animals in a state of health, the contraction of the ventricle is scarcely finished before the auricles contract, and the moment the jet of blood enters the cavity of the ventricle it expands, and the diastole is quickly completed and succeeded by the systole. And here nothing like a suction power is exerted by the ventricle, the blood being distinctly projected by the auricle as it contracts. Nor does any pause or period of repose intervene from the commencement of the dilatation till its completion.

But when a pause occurs during the diastole of the ventricle, that is to say, when the action of the heart is comparatively slow, the diastole of the ventricle is considered to follow the

systole, and not to preeede it,[a] because the first stage of the dilatation and the pause is completed before the auricles contract, and shoot down to the foramen of the ventricle to complete the second stage of the diastole, on which the ventricle immediately contracts.

Haller, who seems to have viewed the action of the heart when it was slow, and who strongly maintained the doctrine of the relaxation of the ventricles, enquires the reason of the particular order or occurrence of the movements—that is, why the auricles contract, whilst the ventricles dilate, and dilate whilst the ventricles contract; and then the ventricles repose dilated, and the auricles smartly contract? And Dr. Hope, considers the reason to be that the auricles, which have been refilling during the contraction of the ventricles, are brought to a state of distention, by which they contract at the moment of repose, in order that the ventricles by the additional quantity of blood which they receive from the auricles, may then be distended and stimulated to contract. But according to the views which we have advanced, these movements arise as a necessary consequence from, or are intimately connected with the action of the heart when it is slow; and the movements are performed in a different manner when the action is accelerated; the reason of which movements will become more obvious as we proceed.

This subject, however, will be better understood if we describe a few of the experiments we have performed in our researches on the action of the heart.

If we expose the heart of a living fish, whose gills are well protected by the operculum, enabling them to retain a due degree of moisture, sufficient to sustain the function of respiration for a considerable time, after the animal has been removed from the water—and it is surprising to what extent this power is possessed by some fishes—it will be found that when the effect of the operation has subsided, the circulation will be carried on with energy, and the animal will survive for a time, affording ample opportunity to study the movements of the heart.

July 8.—Denuded the heart of a living fish[b], and carefully observed the action of the heart.

The heart beat at thirty-six pulsations per minute, and the auricle, on contracting, projected the blood into the cavity of the

[a] Dr. Hope on the Heart, p 19.

[b] Commonly termed the *Mud Cat Fish.*

ventricle, which slightly bulged out in the centre, and contracted, the apex being tilted up, and the blood propelled along the bulbus aortæ, the ventricle immediately dilated and a slight pause ensued, during which both auricle and ventricle were quiescent. The auricle then contracted and projected the blood into the ventricle, and the same movements were repeated. After dilatation the ventricle did not move till the auricle contracted, but the auricle which remained dilated, having been refilled with blood from the veins during contraction of the ventricle, contracted shortly after the pause ensued. During contraction the ventricle was drawn up or contracted towards the bulbus aortae; but during dilatation the fibres were stretched out or elongated towards the abdomen; and the contraction seemed to occupy longer time than the dilatation.

The pulsations increased to forty-two per minute, and then the auricle commenced to contract just as the ventricle reached the pause—that is, simultaneously with the completion of the dilatation of the ventricle.

But on the pulsations amounting to fifty per minute, the contraction of the auricle commenced before the dilatation of the ventricle was completed, or before it came to a pause. The moment the auricle contracted and propelled the blood into the ventricle, the dilatation was completed, and the ventricle contracted; and the reason apparently was, that the ventricle was stimulated or excited by the action of the auricle as it projected the blood into its cavity; and in this case there was no pause or period of repose, the act of dilatation being distinctly continuous.

During these movements of the heart the function of respiration was maintained, as the blood passed along the bulbus aortæ with great rapidity to the gills, which were at times moistened with water sprinkled over them; and we observed that when the animal respired, opening and shutting the operculum with vigour, the action of the heart was quickened.

July 4th.—The heart was exposed in another living fish, and the phenomena beautifully seen, as the animal survived long, and the heart continued to act with great vigour, pulsating at sixty and sixty-four per minute.

When the auricle contracted or projected blood into the ventricle, it expanded and bulged slightly out in the anterior parietes, extending its apex rapidly outwards, and then contracted

towards the bulbus aortae, the apex being distinctly tilted up. The contraction was no sooner terminated, and the dilatation commencing, than the auricle again contracted and sent a wave of blood into the ventricle; and the same movements were repeated, and continued without interruption, the ventricle dilating and contracting in quick and regular succession; the contraction of the auricle was now synchronous with the dilatation of the ventricle, and the pause or period of repose entirely disappeared.

On one occasion, when the animal had struggled much, and turned upon its side, the ventricle became empty and quiescent, and we observed, on the animal being re-adjusted, that the moment the auricle contracted and projected blood into the ventricle, it dilated and then contracted; the same effect we have frequently seen produced in other instances, from which we inferred that the blood projected by the auricle exerts an influence on the dilatation of the ventricle.

In other fishes, on rapidly denuding the heart, we have found the auricle, ventricle, and bulbus aortæ acting with great energy, at the rate of eighty pulsations per minute; the auricle contracting towards the orifice of the ventricle, and the ventricle contracting towards the bulbus aortæ, on which occasion there was no pause nor anything approaching it, in the dilatation of the ventricle; and no evidence that any blood flowed from the auricle into the ventricle, by a suction power, to fill up a vacuum. But the blood which entered it was distinctly projected from the auricle during its contraction, which was synchronous with the dilatation of the ventricle; hence there was not two stages of the dilatation, but one, and that one rapidly performed.

June 16th.—Denuded the heart of a living turtle,[a] and observed its action. Respiration was not affected, the animal continuing to respire at times, as is usual with cold-blood animals.

After the operation the heart beat at sixteen pulsations per minute.

In the Turtle, the auricles, on contracting, shoot down in a lateral direction to the foramen of the ventricle, leaving vacant a space at the extremity of each to the extent of one-fourth of an inch, which they again cover as they fall back, and stretch out their parietes during dilatation. After contraction the auricles immediately

[a] Mud turtle.

dilate, and during dilatation the blood flows into them from the venous trunks; then they remain distended and quiescent for an instant, till the next contraction.

When the ventricle contracts its base is raised up towards the bulbus aortæ, along which it propels the blood; and this vessel becomes more curved, hard, and tense at the moment; after contraction the ventricle immediately dilates, and a pause ensues, during which the auricles and ventricle are quiescent. Then the auricles contract and propel more blood into the ventricle, completing the dilatation, or as it has been termed, producing distention of the ventricle, on which it instantly contracts, and again dilates, attaining a pause as before; and these movements continue.

When the heart beat at 22 pulsations per minute, its action was more vigorous then when it beat at 16 per minute,and the pause of shorter duration ; in other words, the auricles contracted sooner, propelling the blood into the ventricle—completing the second stage of dilatation.

The action of the heart having increased to 28 pulsations per minute the auricles contracted as the dilatation of the ventricle attained the pause.

But on the pulsations increasing to 32 per minute the auricles contracted, projecting the blood into the cavity of the ventricle as it dilated or proceeded to a pause. The dilatation was completed, and the ventricle contracted, but no pause occurred—the dilatation consisting of one individual act.

When the action of the heart attained to 36 or 38 pulsations per minute, the contraction of the auricle was synchronous with the dilatation of the ventricle—that is to say, the auricles commenced to contract, and shoot down to the foramen of the ventricle as the ventricle began to dilate. It almost appeared as if the blood which the auricles projected into the cavity caused its dilatation—the ventricle expanding and dilating as the wave of blood entered it. The auricles dilated and received more blood from the veins, whilst the ventricle contracted, and the instant the auricles were refilled with blood they contracted, whilst the ventricle dilated; these movements being performed in rapid and uniform succession. But the contraction of the ventricle seemed to occupy longer time than its dilatation. Then there was no pause, the dilatation of the ventricle consisting of one act—synchronous with the contraction of the auricles.

Neither the auricles nor ventricle appeared to empty themselves

during the contraction, expelling only a portion of the blood which they contained.

July 21.—The heart of another living turtle was denuded, and the phenomena observed. Respiration continued; and after the effects of the operation had subsided, we examined the action of the heart, and found it 25 pulsations per minute.

The dilatation took place immediately after the contraction of the ventricle, and proceeded to a pause. The auricles then contracted, projecting more blood into the ventricles, completing the dilatation—on which the ventricle contracted.

But when the pulsations attained to 36 per minute, the auricles contracted simultaneously with the dilatation of the ventricle; that is, after the contraction was finished, and the dilatation of the ventricle commencing, the auricles contracted, projecting a wave of blood into the ventricle, and the dilatation was completed. They immediately receded, extending or stretching their parietes outwards, and dilated, receiving more blood from the veins, whilst the ventricle contracted, propelling the blood along the bulbus aortæ. And these movements were continued, the contraction of the auricles coinciding with the dilatation of the ventricle—the pause disappearing—and the dilatation consisting of one act quickly performed; 36 pulsations per minute were the highest attained.

During all these experiments respiration was continued, the animals respiring at times, as is done by cold-blooded animals, and then the action of the heart was accelerated.

When the animal became agitated and struggled much, we have seen the ventricle contract and dilate for several successive times, whilst the auricles remained motionless and distended with blood; but on the auricles contracting, the regular and uniform action of the heart was restored.

As regards the dilatation of the auricles, we cannot suppose that it was produced by the mere influx of blood into the cavity, for it was during the extension of the parietes that the blood flowed from the veins, and the veins have not the power, by the blood which they pour into the auricles, to produce such a movement. It was not like distention, but an actual expanding or stretching out of the parietes of the auricles, as if by an innate power which they possessed.

July 15.—Denuded the heart of a frog which had been reduced to a state of partial asphyxia—carefully guarding against injuring the muscles of the throat, on which the function of respiration depends.

After the effects of the operation had subsided, we examined the action of the heart, and found it 30 pulsations per minute.

The ventricle having contracted, and propelled the blood along the bulbus aortæ, immediately dilated, becoming partially filled with blood, the apex being stretched out or extended lower, a pause ensued, during which the auricles contracted, projecting more blood into the ventricle, which expanded its parietes, and extended its base upwards—thus completing the second stage of dilatation and contraction, and contraction immediately ensued. Sometimes the first stage of dilatation was so closely succeeded by the contraction of the auricles, and increase of blood into the ventricle, that it seemed almost one continuous act. The first dilatation was very short, and quickly performed, and the principal act of dilatation was when the auricles contracted, and projected the blood into the ventricle. It was not distention, but an actual stretching out and expanding of the parietes of the ventricle, so as greatly to enlarge its capacity, and it instantly contracted.

The action of the heart increased to 36 pulsations per minute, and the dilatation of the ventricle was now continuous—no pause—the auricles contracting, and projecting the blood into the ventricle as it dilated and extended its parietes—assuming a dark red colour. It immediately contracted, and these two movements were continued—the ventricle dilating as it received the blood from the auricles, and contracting as it propelled the blood along the bulbus aortæ. In dilatation, the apex of the ventricle descended a little lower, dipping towards the spine, the anterior parietes became protuberant, and the margin of the base was rapidly extended, partially concealing the contracting auricles from the view. In contraction the ventricle became small and pale, being apparently emptied of its blood, and the apex was slightly tilted up. Whilst the heart acted with this degree of vigour, the animal respiring freely and remaining at rest, the pause or period of repose disappeared in the dilatation of the ventricle—the dilatation consisting of one distinct act, because the auricles contracted sooner in the order of time and of rhythm, and as the ventricle dilated.

The animal became restless and agitated, and the ventricle lay contracted and motionless; but on the animal becoming quiescent, the auricles contracted or shot down to the orifice of the ventricle and that moment the ventricle expanded or opened up its parietes, the blood being projected into its cavity. It contracted as the auricles receded or dilated, and the movements were continued in

regular succession, and were always more vigorous when respiration was renewed and continued for a time.

The animal having remained at rest for a considerable time, respiration being maintained with vigour, the action of the heart increased to 44 pulsations per minute.

The instant the auricles dilated, and were refilled with blood from the veins, they contracted or shot down to the foramen of the ventricle, and the ventricle rapidly dilated, opened up, and extended its walls as the blood entered it. It immediately contracted, propelling the blood along the bulbus aortæ; and the same movements were repeated and continued. The dilatation of the ventricle was now synchronous with the contraction of the auricles, and it seemed as if the blood projected by the auricles excited the ventricle to dilate; the instant it touched the ventricle, the ventricle opened up, and expanded its parietes, and was filled with blood. There were thus two distinct forces in operation—the auricles contracting and projecting the blood into the ventricle, and the ventricle expanding its parietes and enlarging its capacity to receive it.

September 12th.—Denuded the heart of a living frog, leaving the muscles of the throat uninjured. Respiration was continued and maintained with vigour.

The heart beat at 60 pulsations per minute; and as the auricles shot down to the foramen of the ventricle, or contracted, projecting the blood into its cavity, the ventricle dilated, its fibres being distinctly stretched out or elongated as usual, it immediately contracted, diminishing in all its dimensions, whilst the auricles dilated. And these movements went on in regular succession, the ventricle dilating as the blood was projected into it during contraction of the auricles, and immediately contracting and propelling the blood along the bulbus aortæ. But after contraction of the ventricle it did not dilate before the auricles contracted; in other words, the contraction of the ventricle was just terminated when the auricles shot down to the foramen of the ventricle, or contracted; and that moment the ventricle dilated, expanding its parietes and extending its apex as the blood flowed into it, and then contracted with great energy, the blood being expelled. The action of the ventricle consisted of dilatation and contraction, maintained without interruption, the dilatation of the ventricle being synchronous with the contraction of the auricles, and its contraction coinciding with their dilatation, the dilatation of the ventricle being one distinct act, without any intervening pause.

October 5th.—Denuded the heart of a living frog, and found the pulsations 80 per minute. Respiration was maintained with energy. The ventricle dilated whilst the auricles contracted and projected the blood into its cavity; and it contracted whilst the auricles dilated, diminishing in all its dimensions, and propelling the blood along the bulbus aortæ. There was no pause or interval of repose between the dilatation of the ventricle and contraction of the auricles. This fact was clearly and distinctly ascertained, on some occasions the ventricle having contracted, and being small and pale, the auricles shot down to the foramen of the ventricle, or contracted; and that instant the ventricle expands or dilates, assuming a florid red colour. But no dilatation of the ventricle took place, and no blood entered its cavity except during contraction of the auricles—whilst they contracted the ventricle dilated, and *vice versa*—the movements being repeated and continued in quick and alternate succession.

On carefully observing the action of the ventricle, it appeared when the ventricle dilated, as if its fibres were stretched out or extended to a certain extent; and then drawn up and retracted during contraction. The dilatation appeared the first or principle act, and the contraction succeeded it.

There was a unison in all these movements. When the action of the heart was increased or diminished a little, the contraction of the auricles which took place immediately on being dilated, was so regulated that it occurred just as the contraction of the ventricle was finished, rendering the dilatation of the ventricle synchronous with the contraction of the auricles; and they were dilated and refilled with blood during the contraction of the ventricle.

The movements of the ventricle then consisted of dilatation and contraction, the former being one distinct and individual act, without an intervening pause. The ventricle dilating and then contracting as a consequence of its dilatation.

During contraction, the ventricle appeared to expel all the blood which it contained, as it became small and pale. But during contraction the auricles expelled only a portion of their contents, as they never appeared to be completely empty.

We may also state, when the heart was quickly denuded in these animals, its action was often observed to be maintained with great vigour. In the fish and the frog the bulbus aortæ contracted immediately after and in unison with the contraction of the ventricle. And in the turtle immediately after contraction of the ventricle, as

the wave ofblood was passing along the aorta or bulbus aortæ, that vessel became more curved, hard, and tense; all of which movements were evidently designed to impart an impulse to the blood in its onward course, as it proceeded to the organs of respiration, or to be distributed throughout the body.

These experiments will enable us to judge respecting the manner in which the dilatation of the ventricle is accomplished, and the action of the heart increased. It appears that when the action of the heart is weak and languid the ventricle dilates without much apparent vigour, and attains a pause, before the contraction of the auricles commences, and completes the dilatation. This is distinctly seen in cold-blooded animals, when the heart pulsates at 20 to 25 per minute. 2nd.—When the heart acts with greater energy, the contraction of the auricles coincides with the pause, or shortly precedes it. And third, when the heart beats with great rapidity, the auricles contract simultaneously with the dilatation of the ventricle; so that no pause, nor anything approaching it, is manifested, but the dilatation is completed by a quick and continuous movement, and accomplished in a much shorter time, than when a pause intervenes, before the auricles contract, and project their blood into the cavity of the ventricle.

What is the cause of this increased action of the heart, the animal remaining in a calm and quiescent state, without manifesting symptoms of agitation or uneasiness? It seems to be intimately connected with the condition of the blood. While the blood continues dark and imperfectly arterialized, the action of the heart is weak and depressed, and a pause occurs during the dilatation of the ventricle, before the auricles contract and project their blood into its cavity. But as soon as respiration commences or is increased, the action of the heart improves, and a pause can scarcely be discovered in the dilatation of the ventricle, the auricles contracting before the commencement of the pause, or coinciding with it. And when respiration is fully established and maintained, the heart pulsates with great vigour and no pause occurs, the contraction of the auricles being synchronous with the dilatation of the ventricle.

On the other hand, if a high rate of speed abates, and the action of the heart becomes less vigorous, the auricles are later in contracting and in projecting their blood into the dilating ventricle, till at length a pause intervenes before the auricles contract.

We perceive then how the action of the heart is adapted to the

different rates of speed in the circulation of the blood, according to the condition of the animal, and the circumstances in which it is placed, and how the circulation is increased in unison with the demands of the system. The auricles contract sooner in the order of time, overtake as it were the ventricle in dilating, or actually commence with it, whilst the ventricle at the same instant manifests vital energy and activity in the increased rapidity with which it dilates, and receives the blood into its cavity.

Let us now enquire how the doctrines we have enunciated apply to the action of the heart in warm-blooded animals, and the phenomena there observed; premising, that the movements of the heart are acknowledged to depend on the same principle in all vertebrated animals; physiologists being agreed that the heart of the frog pulsates in the same manner, and observes the same laws, as the heart of the rabbit, ass, horse, and other warm blooded-animals. Indeed, during the heat of Summer, when the cold-blooded animals assume the physiological condition of the warm-blooded, the action of the heart appears to be identical, not only as regards the principle on which the movements depend, but the quickness and rapidity with which they are executed and maintained—the pulsations in many of them amounting to 70 or 80 per minute.

Dr. Hope informs us, in his experiments on the ass, whilst investigating the sounds of the heart, he found that, when its action fell to the natural standard, from 40 to 50 beats a minute, the pause occurred during the dilatation of the ventricle. "Three motions," he states, "could be distinctly recognized, namely, the auricular systole, the ventricular systole, and the ventricular diastole."[a] Now, we know that during the auricular systole the blood is projected from the auricles into the ventricles; and during the ventricular systole the blood is propelled from the ventricles along the aorta and pulmonary artery; and the ventricular diastole is the dilatation of the ventricle terminating in the pause.

He also states, in another part of his work, that "when the animal which was the subject of experiment, regained the slightest degree of sensibility, the action of the heart was so violent, convulsive, and rapid, as to present the appearance of alternate action described by Majendie;" or, in other words, that a pause could not be satisfactorily recognized during the dilatation of the ventricles. And "that in small animals also, as rabbits, whose pulse beats 150 to 200 a

[a] Dr. Hope on Diseases of the Heart, p. 16, 17.

minute, the same appearanee is generally presented, even though they have been eompletely killed, for the interval of repose is too brief to be appreciated by the eye." "Nay, in asses poisoned by woorara, much the same appearance is presented, whenever the pulse is accelerated 20 or 30 beats above its natural standard of 40 or 50, the contraction of the auriele, then beeoming more active and extensive, and eneroaehing so much on the interval of repose as to render it indistinet to an unpraetised eye. I am therefore inelined to think that during palpitation or unnaturally aecelerated aetion, the period of repose aetually is encroached on."

From these statements it appears that Dr. Hope was unable to perceive the pause or period of repose in the action of the heart in warm-blooded animals, when it was rapid and amounted to 50 beats and upwards a minute; and the reason is, that aeeording to a general law in the aetion of the heart, when the cireulation is maintained with vigour the pause does not exist, but disappears. It can be satisfactorily shown that in this condition of the system not only is the pause or period of repose eneroached on, but the contraetion of the auricles, as we have seen, anticipates that period, and takes place simultaneously with the ventricular diastole. A fact whieh has been distinetly recognized by many physiologists in their experiments on the aetion of the heart in warm-blooded animals.

To illustrate this subjeet let us consider the action of the heart in some warm-blooded animals when it is slow and the pause visible, and then where it is aecelerated—remembering that the movements of the auricles are simultaneous, as well as the movements of the ventricles; and that the deseription of one comprises that of the other.

The ventricles contract and propel the blood along the aorta and pulmonary artery, and the ventrieular diastole immediately takes place, during which there is an influx of blood from the aurieles to the ventricle partially filling it; a pause ensues, and the aurieles contract, propelling more blood into their respeetive ventricle, which expands its walls as the blood enters it, becoming fully dilated; and iustantly contraets, propelling the blood along the aorta and pulmonary artery; the ventrieular diastole again takes place, and the movements are eontinued. But on the aetion of the heart becoming aceelerated, instead of a portion of blood passing from the auricles to the ventriele, partially dilating it, it is all projeeted by the contraction of the auricle, eompleting the diastole at

once, instead of two successive stages; and the same movements are repeated and continued without intermission. What is the consequence? The auricles contract immediately after the contraction of the ventricles is finished, and not as formerly, after the completion of the first stage of the dilatation, which circumstance annihilates the pause; and as the dilatation of the ventricle is now completed at once, and synchronous with the contraction of the auricles, it may be considered in order of rhythm and of time to precede the next ventricular systole, so that the movements of the ventricle are converted into the diastole and the systole; during the former, the blood is projected by the auricle into the cavity of the ventricle; and during the latter, the blood is propelled by the ventricles along the aorta and pulmonary artery.

Dr. Hope, and the physiologists who adopt his views, consider the dilatation of the ventricle during the first stage, as it proceeds to a pause, to occur after the systole; and the second stage of the dilatation, which is connected with the contraction of the auricles, to precede the systole. The first stage of the dilatation he views in relation to the preceding systole, and the second stage in relation to the succeeding systole. But if during the vigorous action of the heart in warm-blooded animals the contraction of the auricles coincides with the diastole of the ventricle, and this be completed at once, and not at two successive stages—we are entitled, on the same principle as that adopted by Dr. Hope to consider the diastole to precede the systole—that is, to view it in relation with the succeeding systole; and this is, undoubtedly, what took place in the case of the child, where the heart was protruded without the walls of the chest, and the action was so carefully observed by Cruveilhier. The contraction of the ventricles is stated to have been precisely synchronous with the dilatation of the auricles; and the dilatation of the ventricles to have been performed at the same time with the contraction of the auricles; no period of repose intervening between the two sets of actions;[a] and Majendie states:—"If the heart of a living animal is denuded, we easily see that the auricles and ventricles contract and dilate alternately. These movements are so arranged that the contraction of the auricles takes place simultaneously with the dilatation of the ventricles, and *vice versâ;* that the contraction of the ventricles coincides with the dilatation of the auricles." And our views are to the same effect.

[a] Carpenter's Physiology.

We have denuded the heart of living warm-blooded animals, and carefully observed its action. We have found the pulsation in some cases 90, in others 120, &c., per minute; but we could only recognize two movements in the ventricle, namely, its dilatation and contraction. The dilatation took place simultaneously with the contraction of the auricles, and the systole coincided with their dilatation. There was nothing like an intervening pause, or anything approaching it, in the dilatation of the ventricle.

These facts, established by careful observation, undoubtedly prove that when the dilatation of the ventricle is synchronous with the contraction of the auricles, being completed in one act, it must be considered to precede the ventricular systole, and not to succeed it.

This view may appear at variance with the fact that the second sound of the heart which immediately follows the first is usually considered as coinciding with the ventricular diastole, when the auricles are considered to contract a little later, and to be quickly succeeded by the contraction of the ventricles. In explanation of which we must remember that when the ventricles contract and propel the wave of blood along the aorta and pulmonary artery, the contractile or elastic power which these vessels exert in assisting the circulation forces a portion of the blood against the semilunar valves and produces the second sound the moment the ventricular systole ceases or the *vis a tergo* is withheld. In the fish and frog the bulbus aortæ contracts immediately after the contraction of the ventricle, and assists in propelling the blood forwards. And in the higher order of animals the contractile or elastic power possessed by the aorta or pulmonary artery produces the same effect; so that we perceive how the second sound quickly succeeds the first. And if we adopt the more recent view,[a] that the first sound of the heart is produced chiefly when the blood from the ventricle enters the aorta and pulmonary artery, we are enabled to explain not only how the second sound quickly follows the first, but how the greater interval elapses between the occurrence of the second and that of the first sound—the period of silence in the healthy action of the heart.

With the second sound of the heart commences the dilatation of the ventricles, and simultaneously with this the auricles contract; and as the blood is projected into the ventricle it expands, swells out, and becomes freely dilated. Here the act is more prolonged

[a] Carpenter's Physiology, page 417.

than during the first stage of dilatation, because the whole of the blood that enters the ventricles is projected by the auricles. And the interval is greater between the commencement of the contraction of the auricles and the contraction of the ventricles; in other words, the full dilatation of the ventricles is completed—in unison with the contraction of the auricles—and then the ventricle contracts.

But how do these views harmonize with the description that has been recently given of the direct mitral murmur, that is the murmur produced by contraction of the mitral valve, and manifested when the blood flows from the auricle into the ventricle? It is well known that this murmur has generally been associated with the second sound of the heart;[a] because it was believed that then the ventricle rapidly dilated and admitted an influx of blood from the distended auricles. But it was considered that though the contraction of the valve might exist to a considerable extent, the murmur was of rare occurrence, owing to the weakness of the current of blood flowing from the auricle into the ventricle, preceding the pause or rest of the heart. And it was also maintained, that when the auricles contracted the force which they exerted was small, and the ventricle being already full the resistance required to be overcome before an extra quantity of blood could enter the ventricle necessarily retarded the force and velocity of the current, and consequently weakened or suppressed the murmur.

But Dr. Gairdner, as the result of his pathological researches, is decidedly of opinion that the direct mitral murmur is of frequent occurrence, and precedes the first sound of the heart, rather than succeeds the second sound, and that its real place in the rhythm of the heart is misrepresented when it has been viewed as a diastolic murmur, and not as produced whilst the auricles contract and transmit the blood into the ventricles. Hence he has termed it an auricular-systolic murmur. But as Dr. Gairdner at the same time admits that the diastole and the pause precede the contraction of the auricles, and as, according to that physiological view of the action of the heart, one-eighth of a beat is allowed for the auricles to contract and pour the blood into the ventricles—which at the rate of 60 pulsations per minute is one-eighth of a second, and at 90 pulsations per minute is one-twelfth of a second—it is difficult to perceive how this corresponds with the character of the murmur, as prolonged, and extending through the pause, and at times

[a] Dr. Hope on Diseases of the Heart, p. 78 and 388.

appearing to arise from the second sound. Dr. Gairdner describes the murmur in Case I. "as a pure auricular-systolic murmur, extending, however, through the pause, and, therefore, at times appearing almost to spring from the second sound, increasing afterwards in intensity, so as to abut sharply and with emphasis upon the first sound." And in the second case he says, "the other murmur is clearly endocardial—that is, the auricular-systolic murmur, being long and rough, extending quite through the pause, and almost beginning at the second sound."[a]

We quite agree with Dr. Gairdner in considering the direct mitral murmur an auricular systolic murmur, but we submit that the description which he gives of it, and which is no doubt perfectly correct, goes far to support the view, that the diastole of the ventricle is synchronous with the contraction of the auricles.

In reference to the argument that when the diastole of the ventricles is synchronous with the contraction of the auricles, it must be considered to precede the systole, since it is admitted that the auricles contract before the ventricles, we may further state: it appears to be the normal action of the heart, that the auricles dilate whilst they receive the blood from the veins, and then contract in expelling it into the ventricles; and if the dilatation of the ventricles be simultaneous with the contraction of the auricles, it follows that this act is not relaxation of the muscular fibres, but must be viewed as a distinct and definite power possessed by the ventricle, by which it opens up and expands its parietes, as the blood flows into its cavity; and then it contracts and projects the blood along the arteries, so that we have an active power exerted both in the dilatation of the ventricle and in its contraction, which alone, in our opinion, is consonant to the high rate of speed maintained in the movements of the heart, the pulsations amounting to 80, 90, or 100 per minute, and even 200 per minute, as in the menoculus pulex; and the character of the movement equally indicates an active power, the dilatation being distinctly continuous, of a unique character throughout, from its commencement to its completion. And the same fact is also clearly manifested by the force and vigour with which the ventricle dilates in the higher order of animals. Hence we conclude that the diastole is produced by an actively dilating power inherent in the ventricle.[b]

[a] Medical Times and Gazette, Oct. 29th, 1864.

[b] Dr. Williams remarks, "That the ventricles have an actively dilating power, was held by Bichat, Pechlin, Carson, and others; and even by Lænnec; and although

Professor Cruveilhier states that the diastole of the heart of the child was performed with the power and energy of an active movement, being sufficient to force open the hand that was closed upon it.

From these researches and statements, we think, we are warranted to conclude that when the action of the heart is vigorous, and respiration fully mantained:—1st. The dilatation of the ventricles is synchronous with the contraction of the auricles. 2nd. That no pause or interval of repose occurs during the dilatation of the ventricle. 3rd. The diastole of the ventricles precedes the systole. 4th. The diastole is performed with a power and vigour that affords every indication of a vital active movement.

With regard to the manner in which dilatation of the ventricle is accomplished when no pause occurs—the ventricle must either be possessed of a power within itself by which it attains its maximum of dilatation in unison with the contraction of the auricles, but independent of its influence. For if it precede the contraction of the ventricle, as it undoubtedly does, it cannot be considered the relaxation of the muscle, and its returning to a state of rest. Or the contraction of the auricle by the blood which it projects into the cavity of the ventricle must also stimulate the parietes to extend their fibres and complete the dilatation. But whatever view we entertain, it is evident, that in either case, an active vital power is exerted by the ventricle during the act of dilatation.

During this state of the circulation, the contraction of the auricles takes place, just as the contraction of the ventricle is concluded; and the moment the blood from the auricles touches the ventricle, it expands, swells out, and quickly attains its maximum of dilatation, which would lead us to believe that the blood propelled by the auricle exerts an influence on the rapidity of the diastole of the ventricle. And we have frequently seen, both in the frog and the fish, when, from the agitations and struggles of the animal, the ventricle had become empty and quiescent, that the instant the auricle contracted and projected blood into the ventricle its parietes expanded—dilatation was produced We have also observed when the auricles have contracted during what is termed the second stage

opposed to what we at present know of animal dynamics, it would be rash to absolutely deny the possibility of its existence . . . whatever be the cause the diastole in large animals is sufficient to force open the hand of a person grasping the ventricles, and it is therefore not surprising that this should have been ascribed to an actively dilating power."—Williams on the Heart, p. 298.

of dilatation, that the blood as it entered the ventricle produced not merely distention but actual dilatation of its walls, the margin of its base being rapidly extended upwards. And in this case the heart beat at twenty pulsations per minute, but respiration was recommencing, the animal respiring slightly at intervals. And the force and rapidity with which the auricles contract, even admitting the great distensibility of the walls of the ventricle, could not overcome the resisting power and contractile energy, so as to produce distension of the ventricle, already partially filled, and the fibres everywhere in contact with the fluid contained, if the parietes did not dilate to receive the blood projected by the auricles. A smaller force could not overcome a greater.

In the fish the auricle is small and weak in comparison of the ventricle. In the frog also there is much difference between the strength of the auricles and that of the ventricle; and in warm-blooded animals the auricles are weak and unsupported by valves behind, and the current of blood which they project seems inadequate to overcome the contractile power of the ventricles if it did not act as a stimulus to their dilatation. The fact is, that in all these cases there is an adaptation in the ventricle to receive the blood which enters it—an opening up—an expanding or dilating power manifested by the parietes the moment the wave of blood from the auricle touches the ventricle; without which power the heart could never beat with the velocity and regularity it does.

When the dilatation of the ventricle is completed without an intervening pause, there are two forces in operation which can be distinctly seen in some animals. 1st. We have the auricles contracting and projecting the blood with great rapidity into the cavity of the ventricle. 2nd. We have the ventricle quickly extending its parietes, and stretching them upwards to complete the dilatation. It appears like a beautiful piece of mechanism—the auricle contracting and pouring the blood into the ventricle, and the ventricle opening up and extending its walls to receive it, and then contracting and propelling it along the aorta, whilst the auricles dilate and receive more blood from the veins.

When the circulation attains a degree of celerity that the ventricles dilate whilst the auricles contract, or as it is termed, that the dilatation of the ventricles is synchronous with the contraction of the auricles, it is evident the ventricle dilates and then contracts, or in other words, the contraction of the ventricle must be considered the result of the dilatation. If we keep this fact distinctly

in view, and remember that we can discern the fibres of the ventricle stretched out to a certain extent during the dilatation, and drawn up and retracted during contraction, it will be seen that the dilatation of the ventricle is as much a vital act as its contraction.

What is the cause of the dilatation of the auricles? It cannot be produced by the force with which the blood is propelled by the veins, for the venous trunks contract but slightly, and the energy with which the diastole is performed excludes the idea of relaxation, affording every indication of a vital movement. But it appears to be much influenced by the quality of the blood that passes through the heart; for when more duly arterialized blood begins to circulate, the auricles dilate as well as contract with greater vigour. What is the cause of the contraction of the auricles? Is it that, being fully dilated, they are excited to contract? Then, why do they remain for a time filled with blood when the action of the heart is slow? There must be an intimate relation between the quality of the blood and the contraction of the auricles; for when the blood is imperfectly arterialized, they remain quiescent for a little after dilatation has taken place. But when the blood is more duly arterialized, they contract immediately on being dilated; and all this is produced whilst the animal remains at rest, only that the respiration has commenced and been carried on for a time.

We are well aware that the muscular fibres of the heart are considered to be so arranged as to produce contraction of the ventricle, but not to account for its dilatation. But great difficulty was experienced by the late Dr. Duncan, and also the late Dr. John Reid, in unravelling the muscular fibres of the heart in warm-blooded animals, so as to determine their specific action; and we have not as yet been able, from the arrangement of the fibres, satisfactorily to account for the tilting up of the apex of the heart during contraction of the ventricle. And though apparently opposed to the doctrine of muscular contractility, we are decidedly of opinion, from the evidence adduced, that the diastole of the heart depends on an actively dilating power—which power is clearly manifested during increased respiration, vigorous exercise, mental excitement, or whenever the action of the heart is accelerated.[a]

[a] We may observe, that continued and increased action does not diminish the power of muscular contractility in the involuntary, as in the voluntary muscles of the body. "In the case of moderate exercise—of mental excitement—and in the course of different febrile and inflammatory diseases—we have examples of greatly increased

What is the cause of the continued action of the heart? This is a question that has much engaged the attention of physiologists. The heart it is well known will pulsate for hours in some cold-blooded animals after life is extinct and the circulation has ceased. The pulsations are continued at intervals after its removal from the body, when no stimulus is apparently present to excite its movements. We have seen in the fish an irregular action of the heart maintained for several hours after life was extinct, the auricle contracting frequently and the ventricle only at times. And these movements continued till the parietes began to dry and shrivel up, and then, after remaining quiescent for a time, a slight movement commenced in the central portion of the auricle, and extended to the ventricle, producing a slight contraction in that part of the ventricle in connexion with the auricle. After a short interval, when all was apparently quiescent, a slight movement was observed in the apex of the ventricle which extended an impulse to the base, and a similar movement, or partial contraction, occurred for several successive times, at the interval of about 30 seconds, the auricle remaining perfectly quiescent. If it be maintained that the atmospheric air acts as a stimulus to the heart when it is empty and deprived of blood, how does it happen that its pulsations are equally distinct and continued under the exhausted receiver of an air-pump? These facts would seem to imply that the heart possesses an inherent power of movement, and that its proper stimulus is the blood—the action of the heart being decidedly affected by the condition and quality of the blood that circulates through the system. Dark and unarterialized blood retards its movements, whilst duly arterialized blood increases its action; under its influence both the auricles and ventricles dilate and contract with great energy and vigour.

action of the heart, without any decidedly debilitating effect on the heart's action necessarily following. The doctrine of increased action, necessary in all cases, lowering or exhausting the irritability of muscles, particularly as applied to the involuntary motions, is therefore by no means an established principle."—Dr. Alison's Physiology, page 39.